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Extended Atmospheres of Outer Planet Satellites and Comets

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16. Abstract

Collisions between neutral hydrogen atoms in the interstellar medium and those in the so-called Titan hydrogen torus may provide an additional lifetime sink for atoms in the Saturn environment. Progress toward re-sorting the Voyager UVS scans of neutral hydrogen in the Saturn system to enable both a factor of two increase in the amount of data to be analyzed as well as to help identify near-Titan hydrogen is discussed herein. Progress toward development of the cometary carbon and oxygen models is also discussed and a preliminary model run for the H_2O source of cometary oxygen is presented.

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I. Program of Research for the Third Quarter

Research activities during the third quarter have concentrated on (1) early development of models for cometary carbon and oxygen, (2) beginning a paper which documents the AER particle-trajectory model, (3) identification of a new possible lifetime sink for neutral hydrogen in the Saturn system, and (4) initiation of a new processing step at LPL for analysis of Voyager UVS Lyman-α scans of hydrogen in the Saturn system.

1. Cometary Atmospheres

Work has begun in the area of modeling the extended atomic carbon and oxygen clouds in comets. The spatial distributions of cometary C and O have been observed in the emissions at 1657 Å and 1304 Å respectively in Comet Kohoutek 1973XII (Opal and Carruthers 1977). Smith et al. (1980) have measured the distribution of carbon in Comet West 1976VI at 1657 Å and also C('D) at 1931 Å. Weaver et al. (1981) have reported IUE observations of C and O in a few faint comets, but these were only single nucleus-centered brightness values.

As for most cometary observations, all of these data have been analyzed in terms of Haser's model, which cannot be used to provide reliable physical information regarding lifetimes, outflow velocities, or exothermic ejection velocities. Using the particle-trajectory method, we can provide a physically realistic framework in which true source and sink characteristics and their spatial and temporal dependencies can be understood.

To the best of our knowledge, the sources of the bulk of the observed carbon and oxygen lie in the photolysis of cometary H_2O, OH, CO and CO_2 (Delsemme 1982). Carbon production from the visibly prominent carbon radicals, CN, C_2, and C_3, only accounts for a minor fraction of total carbon in comets (Feldman 1978, A'Hearn and Feldman 1980). Although the existence of CO_2 ice in comets is strongly suggested by the presence of CO_2^+ in ion tails, Feldman (1978) has put forth some convincing arguments in favor of CO as the ultimate parent of much of the cometary carbon. With this in mind, we have constructed photochemical scenarios for the production of carbon and oxygen with H_2O, CO and CO_2 as primary parent molecules and will constrain our conclusions by the appropriate observations.

Table 1 shows a list of the branching ratios and exothermic velocities for the production of C and O from H_2O, CO_2 and CO. The total photolysis rates for these three parents are $1.2 \times 10^{-5}\ s^{-1}$, $2.0 \times 10^{-6}\ s^{-1}$ and $6.5 \times 10^{-7} s^{-1}$, respectively. The data for CO and CO_2 are from Huebner and Carpenter (1979); those for H_2O are from Festou (1981) to which the O('D) branching ratio has been updated (Slanger 1982).

The H_2O source of cometary oxygen has already been implemented in the particle-trajectory model and a test run, based on the geometry and H_2O production rate corresponding to the hydrogen observation of Comet P/Encke by the Pioneer Venus Orbiter, has been made. Similarly to the hydrogen Lyman-α case, the emission rate factor (g-factor) for the oxygen 1304 Å triplet is highly dependent on heliocentric velocity. The 1304 Å emission is excited by resonance scattering with the solar oxygen emission as well as by fluorescence by solar Lyman-β. This velocity dependent g-factor as calculated by Feldman (1982) has been adopted in the model and is shown in Figure 1.

The modeled 2-D sky plane view of the 1304 Å oxygen emission as viewed for the Pioneer Venus geometry is shown in Figure 2. The nucleus-centered slit position of the Pioneer Venus OUVS instrument should have recorded a slit-averaged intensity of only 1.6 Rayleighs which is unfortunately one order of magnitude below the background noise limit for the two hour integration attempted by Pioneer Venus on 15 April 1984.

2. <u>Titan Hydrogen Torus</u>

During this past quarter, W. Smyth visited D.E. Shemansky at the Lunar and Planetary Laboratory of the University of Arizona in Tucson to further our ongoing collaborative effort to analyze the hydrogen Lyman-α emissions from the Saturn system obtained by the UV instrument aboard the Voyager spacecrafts. The Titan hydrogen torus is expected to be an important source of H atoms for these observed emissions. By comparison of the Titan torus model calculations, to be performed at AER, with the Voyager data, the Titan source rate will be evaluated and other possible non-Titan sources will also be investigated. The visit to Tucson was most productive. Two important aspects that have resulted from this visit are discussed below.

A primary subject of the discussion during the Tucson visit was the Voyager 1 data set, which consists of east-west slit scans of the Saturn system. The Lyman-α radial brightness profile obtained from about 25 percent

of these scans was reported earlier by Broadfoot et al. (1981). Additional processing that has been completed in this quarter by Shemansky now makes available for our analysis more than 50 percent of these scans. This increase in available information will not only improve the statistics for newly constructed Lyman-α radial brightness profiles but will also be used to determine if there is a heightened signal at Titan's location in the east-west scans. The analysis of the scans for this signature will be completed by Shemansky early in the fourth quarter and will be utilized in our future model-data comparisons.

A new lifetime sink for the hydrogen torus was also identified as a result of the Tucson visit. This sink is the removal of H atoms from the torus by elastic collisions with the rapid flow (~20 km s^{-1}) of the interstellar medium (mostly H atoms) through the solar system. Most torus H atoms involved in these collisions can gain sufficient additional energy (~0.3-0.03 ev) so that they are gravitationally lost from the Saturn system. The new lifetime mechanism for torus atoms thus depends upon the elastic cross-section between hydrogen atoms for transfer energies that are relatively small. This cross-section for such small energy transfers is fairly large and is currently being evaluated by Shemansky. The torus lifetime for this cross-section is expected to compete with the H-atom lifetimes produced by the planetary magnetospheric plasma and the solar wind ($\gtrsim 1 \times 10^8$ sec), both reviewed in the second quarter progress report. The potential impact of this new lifetime process may be threefold: (1) to reduce the long integration times for H-atom trajectory orbits that would otherwise be required to model the torus properly, (2) to play a significant role in regulating the number of H-atoms in the torus, and (3) to provide a 30 year modulation of the number of H-atoms in the torus because of orbital motion (~9.6 km/sec) of Saturn about the Sun. Because of the first of these potential impacts, further testing originally scheduled this quarter for the Titan hydrogen torus model to investigate more efficient ways to calculate very long integration time trajectories was postponed.

II. Program of Research for the Fourth Quarter

Research activites in the Saturn system will involve further evaluation of the new lifetime sink for the Titan hydrogen torus and its incorporation into the Titan torus model. Voyager 1 data for east-west scans of the hydrogen Lyman-α brightness profile will be obtained from Shemansky and steps to analyze these data will be initiated.

Research activities in the area of the extended cometary atmospheres will involve continued development of the carbon and oxygen models, continued work on the paper which documents the comet model, and preparation for the September 1985 Pioneer Venus Orbiter UVS observations of Comets P/Giacobini-Zinner and P/Halley.

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Table 1

Production of Cometary Carbon and Oxygen

Reaction	f_o[a]	v_o[b]	f_c[a]	v_c[b]
$H_2O + h\nu \rightarrow H_2 + O(^1D)$	.034	1.6	–	–
$\rightarrow H + OH$; $v_{OH} = 1.2\text{–}1.8$ km s^{-1}				
$OH + h\nu \rightarrow O + H$	.907	.5	–	–
$CO + h\nu \rightarrow C + O$	.434	3.66	.434	4.88
$\rightarrow C(^1D) + O(^1D)$	.064	5.52	.064	7.36
$CO_2 + h\nu \rightarrow O + CO$; $v_{CO} = 3.71$ km s^{-1}	.456	6.50	–	–
$CO + h\nu \rightarrow C + O$	.202	3.66	.202	4.88
$\rightarrow C(^1D) + O(^1D)$	.030	5.52	.030	7.36
$\rightarrow O + CO(a^3\pi)$; $v_{CO} = 2.18$ km s^{-1}	.138	3.82	–	–
$CO + h\nu \rightarrow C + O$	.060	3.66	.060	4.88
$\rightarrow C(^1D) + O(^1D)$	.009	5.52	.009	7.36

a. Fractional yield of atoms per primary parent molecule
b. Velocity of atom produced in km s^{-1}.

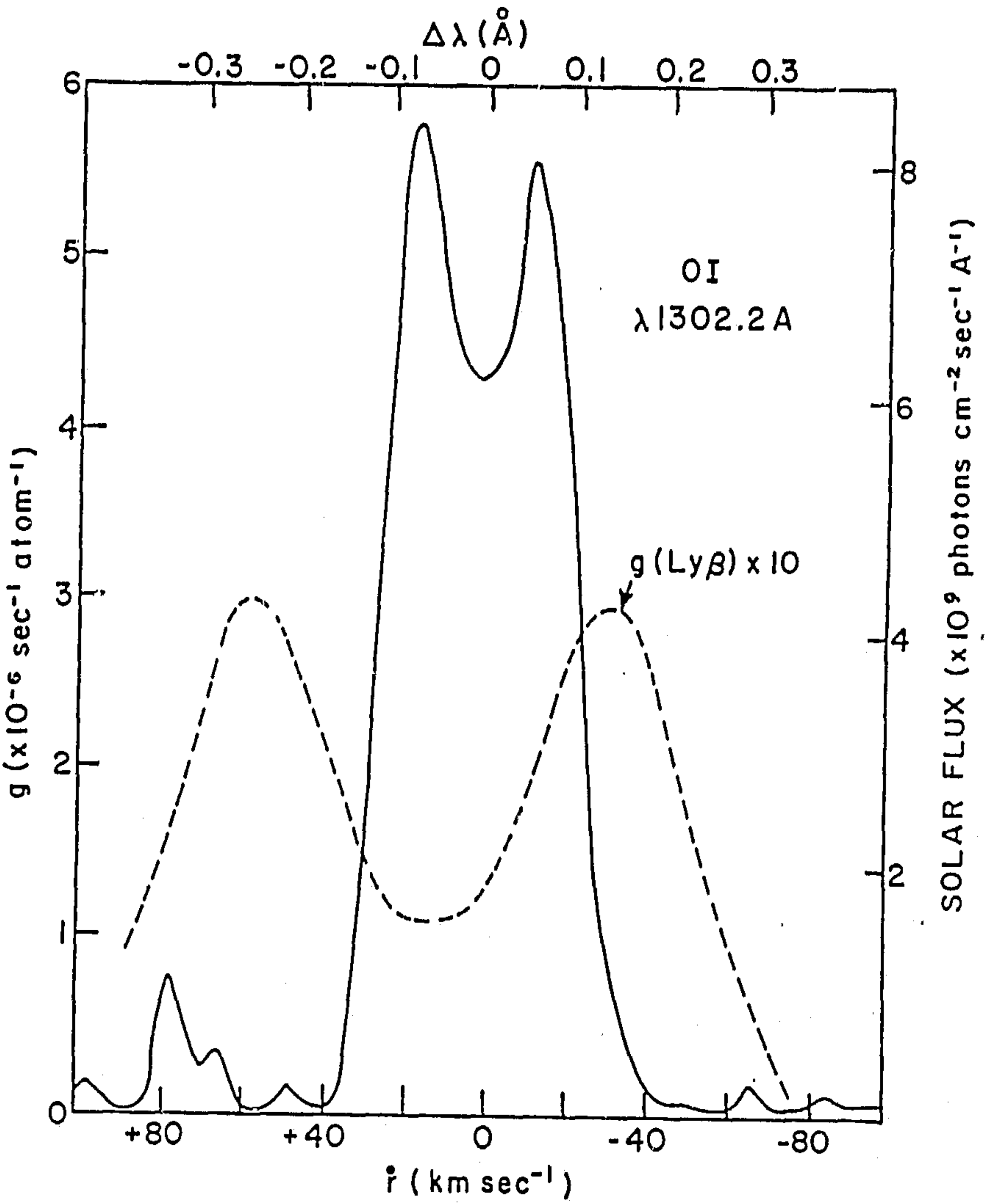

Figure 1
The Heliocentric Velocity Dependent g-factor for the OI 1304 Å Triplet.

These results by Feldman (1982) show the contributions from solar resonance scattering as well as fluorescence by solar HI Lyman-β.

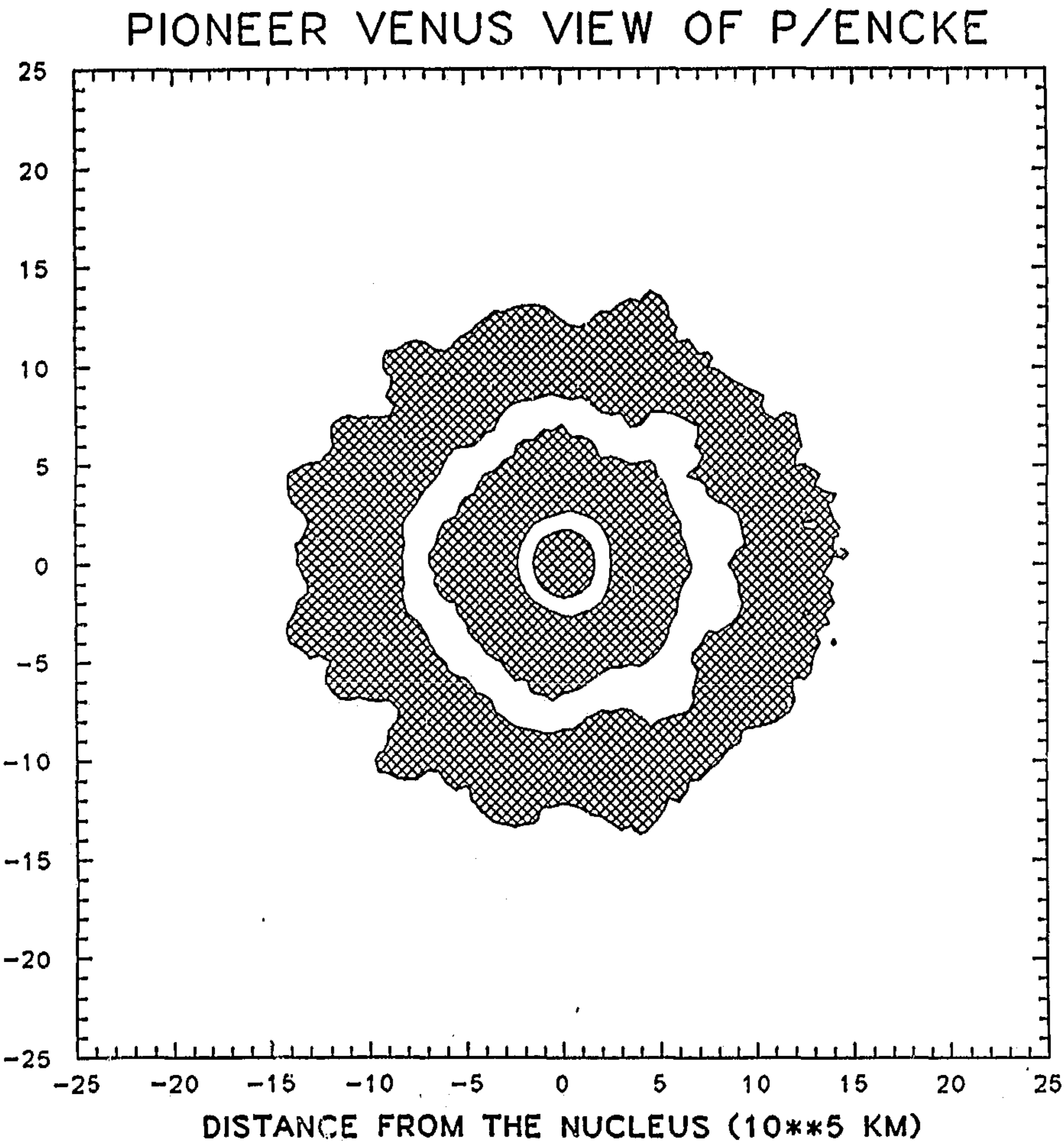

Figure 2
The Modeled OI 1304 Å Emission from Comet P/Encke.

The H_2O source of cometary oxygen corresponding to the Pioneer Venus Orbiter UVS observation (r_H = .58 AU, Q_{H_2O} = 3 x 10^{28} s^{-1}) has been calculated with the particle-trajectory model. The shaded areas correspond to intensities of 0.1-0.5, 1.0-5.0 and >10.0 Rayleighs from the outside to the inside.